

Update for uTracer6 to reduce MOSFET failure and improve accuracy at low voltage and high currents

The uTracer6 V_a and V_s voltage accuracy at voltages below 100V and high currents falls off rapidly.

This is partly due to limited uTracer6 calibration support in most available GUI and partly due to hardware limitations.

To address GUI software limitations today only uTracerJS has the required extra fields to allow calibration of the uTracer6 below 100V at high currents.

Those fields are

For a Stock uTracer6

$V_{adc\ fixed}$

This field corrects for fixed offset voltages in the V_a and V_s hardware adc subsystem.

These offset errors can be easily seen in the debug menu as the voltages for V_a and V_s will be reported as a negative value in place of the correct zero value.

For a stock uTracer6 set $V_{adc\ fixed} = 3.25V$

$R_i\ depend$

This field corrects for resistive losses in the uTracer6 hardware that are not captured by the measurement system and not accounted for in the standard GUI calibration. These resistive losses become a growing percentage of the device under test below 100V at high currents and result in growing errors in the reported value for V_a and V_s .

For a stock uTracer6 set $R_i\ depend = 9\ ohms$

For a uTracer6 with the MOSFET driver update

$V_{adc\ fixed} = 3.0V$

$R_i\ depend$

$R_i\ depend = 3.2\ ohms$

The MOSFET driver update. Why?

1) The stock MOSFET switch in a uTracer6 is a modest unit with a breakdown voltage of 1000V (zero V margin), a current rating of 1.85A and a R_{on} of 6.5 ohms.

The high R_{on} causes loss of accuracy below 100V at high currents.

Most concerning is the safe area if this device is for a 1mS pulse, 1A at 300V.

This means by the data sheet operation with compliance off will leave the switch at risk of failure as while the MOSFET hardware protection limits current it does not limit safe area operation.

Operation with compliance turned on with a uTracer6 will result in the inability to make measurements above about 500mA below 100 volts due to the large voltage droop in the energy storage capacitors.

So in making many high current measurements with a uTracer6 compliance must often be turned off.

The mod will replace this MOSFET with a STW12N120K5, 1200V (good V margin), 12 amp with a R_{on} of 0.62 ohms.

The low R_{on} reduces errors at lower voltages and high current.

Importantly the STW12N120K5 has a data sheet specified safe area of 2.2A for 1mS at 1000V. As the hardware limits switch current to about 1.2A this means by the data sheet the MOSFET should survive a full voltage measurement pulse into a shorted load even if compliance is turned off.

With uTracerJS I_a max and I_s max 1000mA current limit feature, testing will stop if a fault causes a over current event even if compliance is turned off. The result should be far safer testing with or without compliance turned on and ability to use the full 1amp current ability of the uTracer6.

2) The MOSFET driver transistors on a uTracer6 are rated at 100mA DC current with a 200mA pulse rating. The driver circuit as designed has only limited control of Dv/Dt of the MOSFET switch.

In a MOSFET switch Dv/Dt is limited by how rapidly the gate to source charge is altered.

In other words how much current is pulled or pushed to the gate during turn on/off. In the uTracer6 that source to gate charge is the source to gate voltage or 1000V! There is a lot of potential pulse current here. The peak current in the driver transistor is limited in the uTracer6 design by the hfe of the drive transistors a very loose parameter on these devices varying by the data sheet from 110 to 800.

As designed with 10mA of diode current the opto coupler transistor can supply 5mA typical base current to the drive transistor. With a possible hfe of 800 resulting in drive transistor collector currents of 4 amps on a transistor rated at 200mA peak. Even with a typical hfe of 200 the peak collector current can still be 1 amp. This may or may not be OK. My driver transistors failed in my uTracer6 even though the MOSFET did not fail so my take is this is it not always OK as designed.

The update takes two steps to element any possible driver failure.

The BC548 (NPN) is replaced with a 2N4401 a 600mA device

The BC558 (PNP) is replaced with a 2N4403 a 600mA device

The 2N440x devices are also a bit faster than the BC devices.

I added a 18 ohm 1/4W resistor in series with the emitter of each driver transistor.

This sets a deterministic limit to peak driver transistor current and limits MOSFET Dv/Dt to help reduce ringing and ground bounce from excessively fast switching.

The two emitter resistors also prevent any possible "shoot through" currents in the driver transistors due to a driver transistor being slower to turn off than the other driver is in turning on.

3) The uTracer6 is designed on a two layer PCB. Considering the high voltages and currents and resulting fast Dv/Dt events that are possible in a uTracer6 this is in my opinion a aggressive approach to the PCB layout. I am not saying it is wrong and my uTracer6 works pretty well however it does increase risk that ground bounce from the anode and screen pulse sections could end up affecting the PIC.

On a two layer board ground bounce is always a concern with any high current circuit area.

My uTracer6 does from time to time suffer from the PIC hanging during tests and more so at higher voltages. I have no idea as to why this may be but power supply noise or ground bounce is certainly a possible contributing factor. So this fix is under "better safe than sorry" and as I was in there any way why not improve things.

C65 the flying power supply for the MOSFET switch is charged from the +15V rail by T61 being driven low. There is no charge current limit for C65 except the R_{on} of T61 at a typical 6.5 ohms so this is a typical 2 amp current pulse and depending on the MOSFET R_{on} tolerance may be higher still.

There is not large local bypass capacitor for this charge current to prevent the current circulation on the ground tracks resulting in possible ground bounce.

I took two corrective measures for this.

First there is a 10 ohm resistor inserted in the anode of D65 and D85 to limit the charge current to a known value. Second a 22uF 63V capacitor is placed between T61 drain (ground current return point) and the connection point for the 10 ohm resistor to the plus 15 volt rail. This insures any charge current is locally circulated and so is not part of the system ground tracks to limit any ground bounce.

4) The utracer6 cathode return circuit can see over 2amps peak current. The voltage on the cathode circuit is held in place by C44 a 1000uF capacitor. During the test pulse this capacitor charges from the test current and so the cathode voltage rises. The voltage rise is about 1.3 voltage with only the anode port current of 1A and will rise more when the screen current is added. If both ports are near 1 amp (dual rectifier diode testing) the voltage on C44 rises by more than 2 volts.

This results in a loss of voltage across the tube being tested that is not corrected by the software or hardware.

This degrades the uTracer6 Va and Vs accuracy below 100 volts.

I added a 3300uF to 4700uF 25V capacitor in parallel with the presently installed 1000uF capacitor to reduce cathode voltage bounce during testing to typically under 300mV.

Use a good quality capacitor designed for switching power supply use specified for high ripple current and low ESR for the best results.

The details of the MOD

Material needed.

Headers 4 pin, Berg 0.1", Qty 2 needed

Headers 3 pin, machined, Samtec Inc , part number, TS-103-T-A, CONN HEADER VERT 3POS 2.54MM,

Qty 4 needed

MOSFET, ST, STW12N120K5, 12 amp, Qty 2 needed

2N4401 NPN transistor , Qty 2 needed

2N4403 PNP transistor , Qty 2 needed

10 ohm 1/4 watt, 5% or better resistor , Qty 2 needed

18.2 ohm 1/4 watt, 1% watt resistor , Qty 4 needed

22uF 63V capacitor 6.3mm diameter.

4700uF capacitor, 25V, Chemi-Con., EGPD250ELL472MK35H, Qty 1 needed

This at low ESR, high pulse current, capacitor of 12.5mm diameter that will fit on the PCB in place of C44.

Larger capacitors can be soldered beside C44 and are easier to find.

I used a large capacitor from my junk box and left the 1000uF capacitor in place.

The mod is designed to NOT require any tracks to be cut.

The mod was designed to improve the repairability of the uTracer6.

The mod was designed to allow the utracer6 to be easily returned to the stock circuit design if desired at some future date.

Step 1)

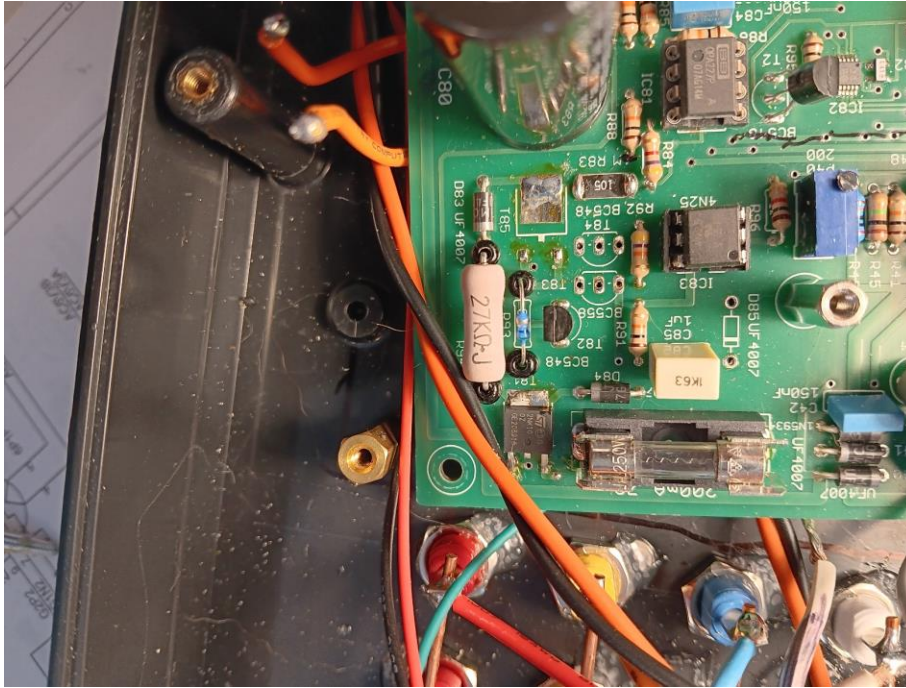
Remove the following in the anode and screen circuits.

T65, T85, T63, T64, T83, T84, D65, D85

T65 and T85 the SMT parts can be tricky to remove without damaging the pads on the PCB.

The mod only uses the large fat pad of T65 and T85 so if the smaller pads become damaged it is not a big issue.

Clean out solder from all the other holes.

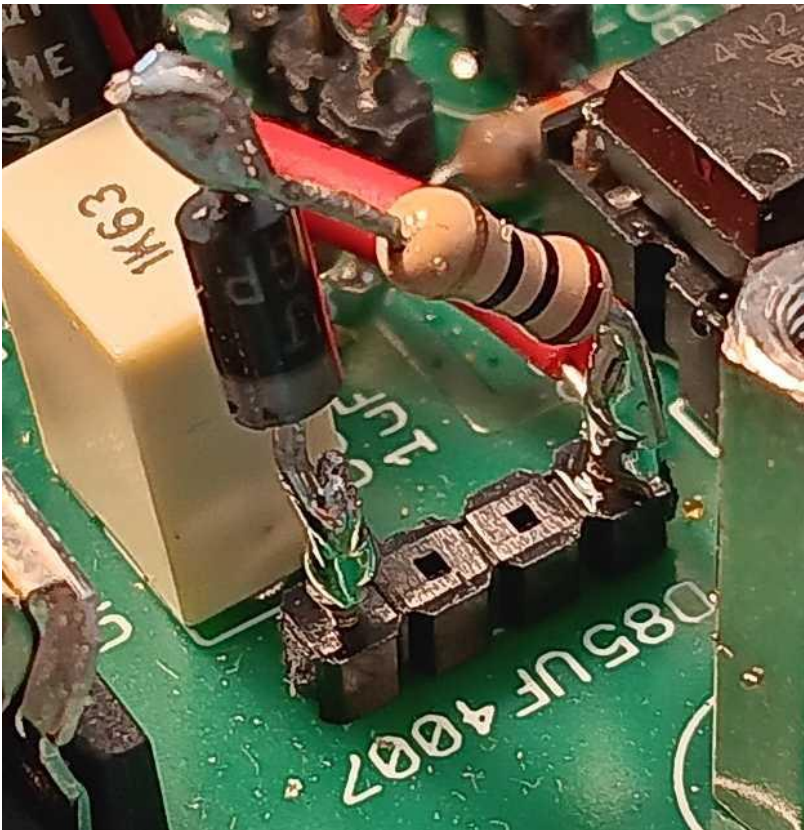


Step 2) Take two berg 0.1 pitch pin strips and cut 4 pin sections. Pull out the two center pins leaving only the two out side pins. Solder this in place of D65 and D85.

Take the diodes removed and solder one 10 ohm 1/4 resistor to the anode (NO stripe) of each diode



Step 3) Solder the diode resistor assembly to the berg pins installed in step #2 at D65 and D85
The diode cathode (band) goes to the berg pin at D65's cathode on the PCB and the new 10 ohm resistor goes to the D65 anode berg pin on the PCB. Repeat for D85.



Step 4)

The berg pins used in step two are a bit to big to fit into the holes for this step.

Take machined pin strips on 0.1" centers and cut to 4 pieces of 3 pin sets.

This allows the driver transistors to be replaced in the future with out touching the PCB.

These pin strips are to be soldered at location T63,T64,T83,T84.

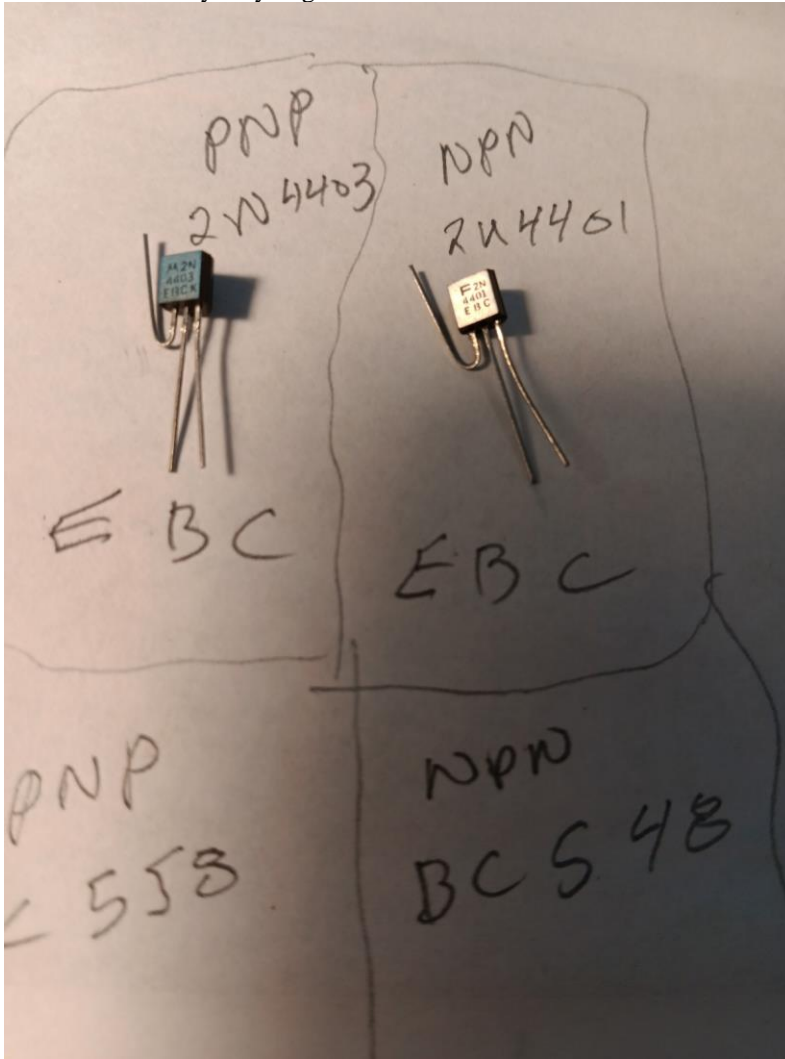
I suggest using the following machined pins or similar.

Samtec Inc , part number, TS-103-T-A, CONN HEADER VERT 3POS 2.54MM

Step 5) Bend upward the emitter lead of both the 2N4401 and 2N4403 transistors as show in the picture.
SEE PICTURE

NOTE The pin out for the 2N4401/2N4403 are the mirror image of the original BC548/BC558 transistors.
This means the new transistors must be installed reversed to how the transistors are shown on the PCB silk screen.

Be careful it is very easy to get confused!!!

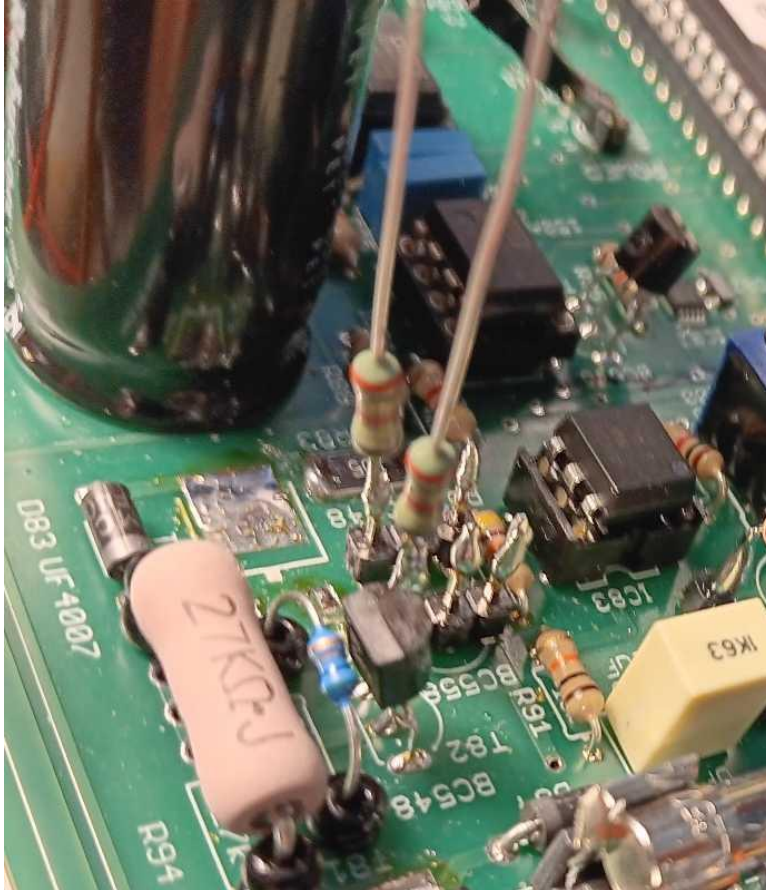


PICTURE

Step 6)

Clip one end of the 18.2 ohm resistors short and solder this end to each of the four resistors to the emitter pins of the machined pin strips soldered on the PCB in step #4.

NOTE The pin out for the 2N4401/2N4403 are the mirror image of the original BC548/BC558 transistors. This means the new transistors are install reversed to how the transistors are shown on the PCB silk screen. Be careful it is very easy to get confused as to where the emitter pin is.

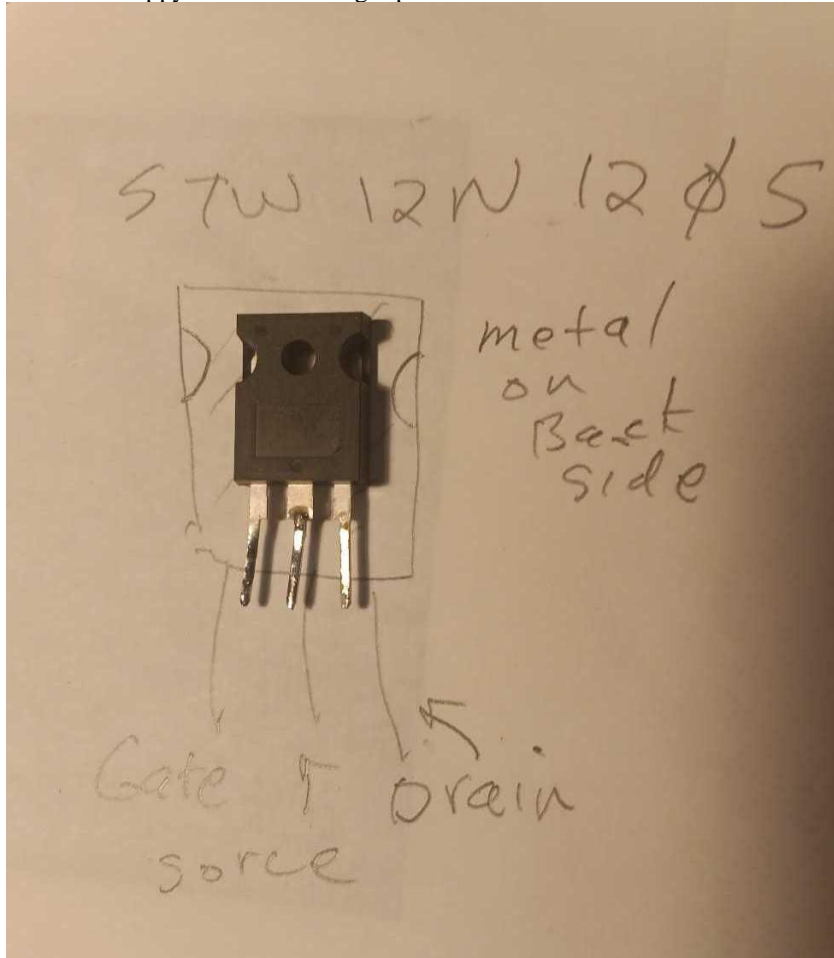


Step 9)

The new MOSFET is a large through hole part and can not be placed on the PCB.

It is mounted on three added wires above the PCB.

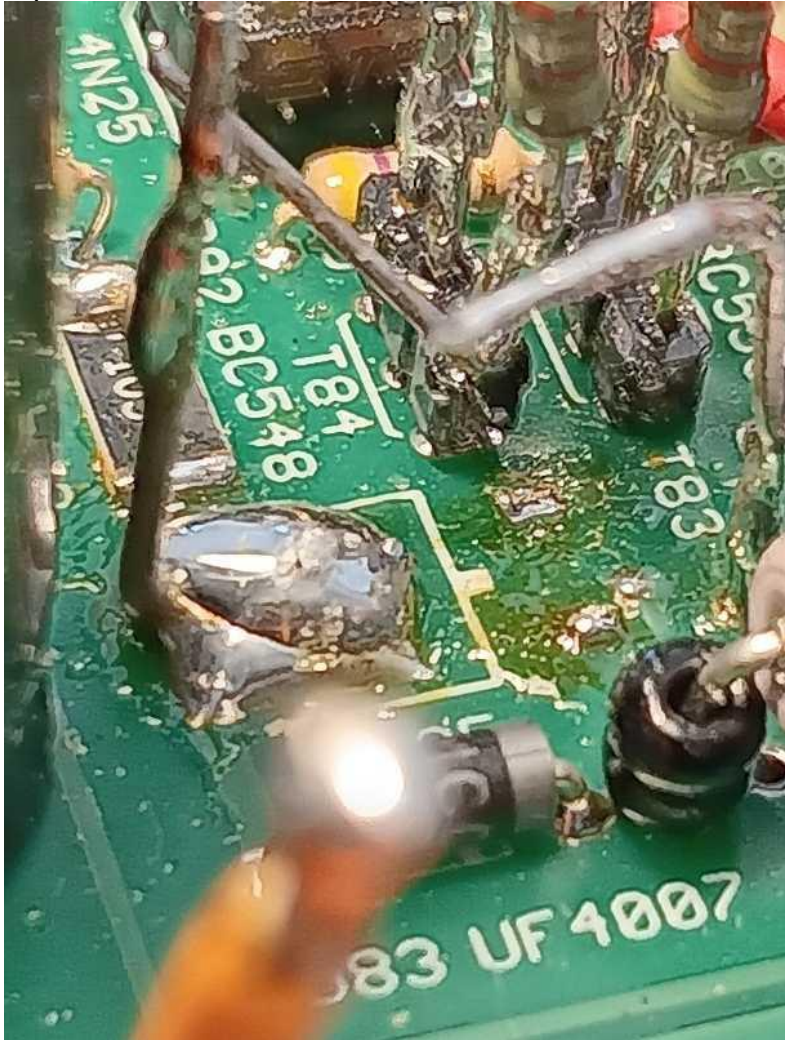
This has a happy effect of making replacement in the future of the MOSFET quick and easy.



Take a #18 bare wire or thick resistor lead and make a small 90 degree bend on one end. Solder this bent end of the thick wire lead to the large pad of T65. The lead is to be soldered standing vertical a little out from the large storage capacitors. The thick wire will provide support for the weight of the new large MOSFET.

This thick wire lead will become the MOSFET source connection (center MOSFET pin)

Repeat for MOSFET T85



Next take a medium thickness wire lead and solder it to the lead of R73 closest to the MOSFET. The lead should be soldered standing vertical.

Do not use too thick a lead as R73 is a very small and thin leaded part (TOO SMALL??).

Repeat for R93



Finally take a thin wire lead and solder it to the machined pin in the PCB that has the 18.2 ohm resistor connected to it at T64. DO NOT solder the lead to the resistor/transistor connection point in the air. This wire lead will be connected to the gate of the new MOSFET. Repeat for T84 machined pin header connection for the 18.2 ohm resistor

Step 10)

As the PCB layout is mirrored imaged from the anode to screen circuits it is very easy to become confused as the what is connected to what on the PCB from the left to the right side of the PCB in the anode and screen circuits. Take your time and check and recheck the connections.

To make the MOSFET connections shorter and more direct the MOSFET at T65 is mounted on the right side (anode circuit) with the MOSFET metal backing facing the storage capacitors.

Solder the thick wire lead added to the large pad of T65 to the new MOSFET's center pin. Take care to mount the MOSFET a little below the top of C60,61. This will insure if the PCB is turned over the MOSFET will not be bent out of position and it's connections broken or shorted.



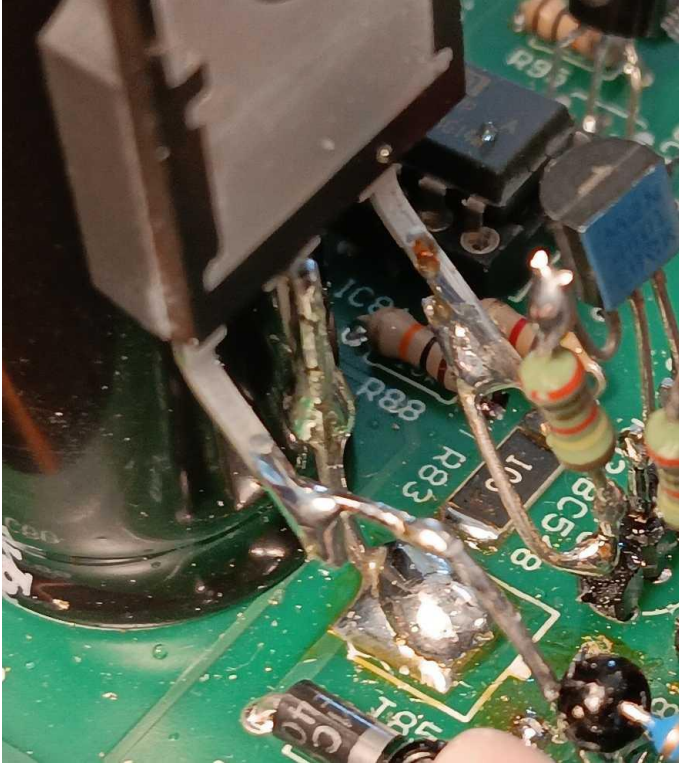
Step 11)

Repeat step #10 on the screen circuit for T85.

NOTE. On the screen side the MOSFET is to be mounted with the metal side facing AWAY from the storage capacitors.

Watch this point!!! The MOSFET metal side must be facing AWAY from the storage capacitors on the screen side.

If you miss this the connections will be reversed for the MOSFET drain and gate pins and circuits will be damaged.



Step 12)

On the anode side connect the right pin (source pin) of the MOSFET for T65 to the wire lead added that goes to R73.

Double check your connection the circuits are unforgiving of errors once the high voltage is applied.

Step 13)

On the screen side connect the left pin (source pin) of the MOSFET for T85 to the wire lead added that goes to R93.

Double check your connection.

Step 14)

On the anode side connect the left pin (gate pin) of the MOSFET of T65 to the wire lead added that goes to the emitter pin of the pin strip soldered on the PCB in step #4 at location T64.

Double check your connection.

SEE PICTURE

Step 15)

On the screen side connect the right pin (gate pin) of the MOSFET of T85 to the wire lead added that goes to the emitter pin of the pin strip soldered on the PCB in step #4 at location T84.

Double check your connection.

Step 16)

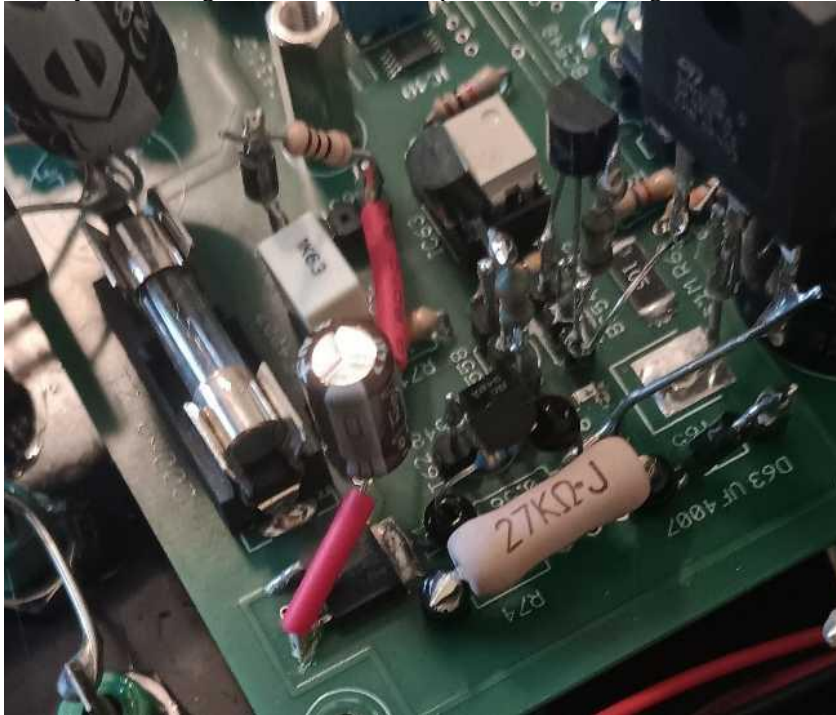
A 22uF capacitor is added between anode connection point at the header added at D65 and the ground connection for the drain of T61 the side right pin.

Adding a bit of sleeving to the capacitor leads will reduce the chance of a short circuit.

The positive lead of the added 22uF capacitor is soldered to the header pin at the PCB for D65 where the new 10 ohm resistor was soldered.

The negative lead of the added 22uF capacitor is soldered to the RIGHT lead of T61.

Be very careful to get the correct side of pin on T61 or damage will result.



Step 17)

A 22uF capacitor is added between screen connection point at the header added at D85 and the ground connection for the drain of T81, the side right pin.

Adding a bit of sleeving to the capacitor leads will reduce the chance of a short circuit.

The positive lead of the added 22uF capacitor is soldered to the header pin at the PCB for D85 where the new 10 ohm resistor was soldered.

The negative lead of the added 22uF capacitor is soldered to the RIGHT lead of T81.

Be very careful to get the correct side of pin on T81 or damage will result.



Step 18)

A 3300uF to 4700uF capacitor is used to add to in parallel or replace C44.

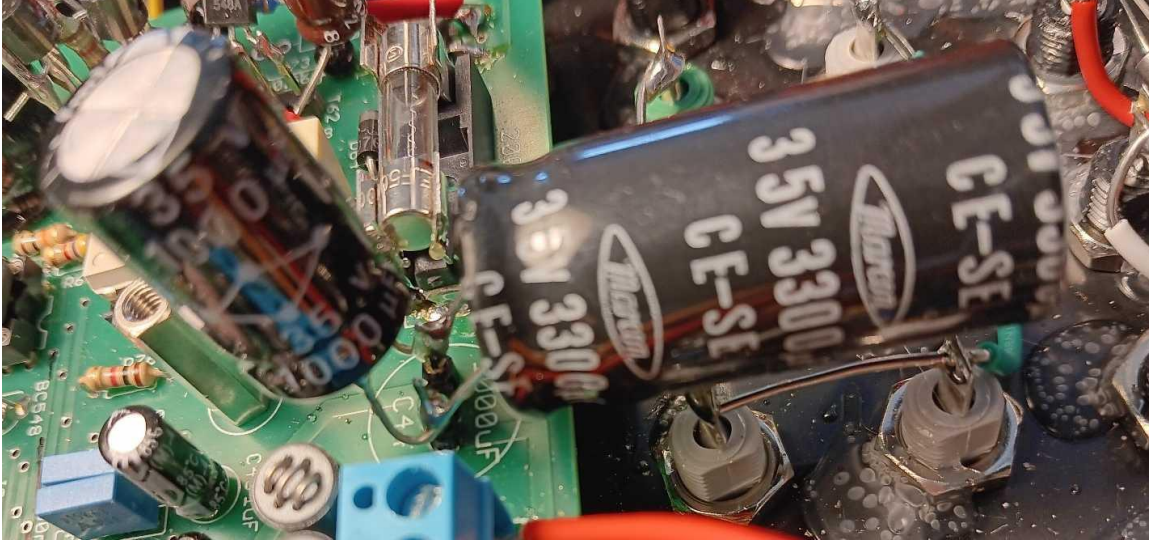
I had a 3300uF cap on hand and so I just added it in parallel to the current 1000uF capacitor at C44.

If you have the 12.5mm diameter 4700uF capacitor specified in the material list then the current 1000uF capacitor at C44 can be removed and replaced with the new 4700uF capacitor.

This looks nicer but there is not any other advance over adding a capacitor in parallel with the current 1000uF capacitor.

The larger the value the better however over 4700uF the capacitor starts to get very large in size.

I also added to header pins to the holes for C44 so future changes can be made without harming the PCB.



I suggest rechecking all connection as the uTracer6 high voltage circuits do not forgive connection errors!

If you find any errors in my instruction please let me know. \

Thanks and good luck.

